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STRUCTURES SUBJECTED TO TIME DEPENDENT  
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ANALYSIS OF SHELL-TYPE STRUCTURES  
SUBJECTED TO TIME-DEPENDENT MECHANICAL AND THERMAL LOADING

A SEMI-ANNUAL STATUS REPORT  
SUBMITTED TO  
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INTRODUCTION

The objective of the present research is to develop a general mathematical model and solution methodologies for analyzing structural response of thin, metallic shell-type structures under large transient, cyclic or static thermomechanical loads. Among the system responses, which are associated with these load conditions, are thermal buckling, creep buckling and ratchetting. Thus, geometric as well as material-type nonlinearities (of high order) can be anticipated and must be considered in the development of the mathematical model.

In the research being conducted in this program two separate approaches are being developed. In one approach an effort was directed toward a development of a general, new kinematically unrestricted, unified thermoelasto-viscoplastic (and thermodynamically consistent) theory which focuses particular attention on the ramifications of the need to properly represent the problem in a rate form. In a second, more traditional approach, available elements of nonlinear mechanics and thermoviscoelastic constitutive equations have been assembled for the use in the solution of problems of interest. The plan being followed will, thus, provide an opportunity to make comparison between the new approach and the



conventional one. The progress completed to date is described in the following section.

### Summary of Progress

As the object of the investigation has been to develop a general mathematical model for analyzing structural response under large transient, cyclic or static thermomechanical loads, the kinematic and kinetic relations must be consistently valid for large displacements and large strains. The above mentioned displacements are not necessarily extensional. Rotations, for instance, might lead to considerable nonlinear effects which are likely to be dominant in the problems under consideration.

A complete true ab-initio rate theory of kinematics and kinetics for continuum and curved thin structures, without any restriction on the magnitude of the strains or the deformation was formulated. The time dependence and large strain behavior are incorporated through the introduction of the time rates of the metric and curvature in two coordinate systems; a fixed (spatial) one and a convected (material) coordinate system. The relations between the time derivative and the covariant derivative (gradient) have been developed for curved space and motion, so that the velocity components supply the connection between the equations of motion and the time rate of change of the metric and curvature tensors. The time derivatives were applied to the basic laws of thermo-mechanics, to obtain the equations of motion, of heat rate and of the compatibility of deformation rates. Finally, the principles of the rate of virtual power and heat were derived, providing sound tools for computational methods.

Five different shell theories (approximations) in rate form starting with the simple Kirchhoff-Love theory and finishing with a complete unrestricted one, were considered.

The metric tensor in the convected (material) coordinate system is linearly decomposed into elastic and plastic (visco) parts. In this formulation, a yield function is assumed, which is dependent on the rate of change of stress on the metric, on the temperature, and a set of internal variables. Moreover, a hypo-elastic law was chosen to describe the thermo-elastic part of the deformation.

A time and temperature dependent "viscoplasticity" model was formulated in this convected material system to account for finite strains and rotations. The history and temperature dependence were incorporated through the introduction of internal variables. The choice of these variables, as well as their evolution, was motivated by thermodynamic considerations.

The nonisothermal elasto-viscoplastic deformation process was described completely by "thermodynamic state" equations. Most investigators (in the area of viscoplasticity) employ plastic strains as state variables. This study shows that, in general, use of plastic strains as state variables may lead to inconsistencies with regard to thermodynamic considerations. Furthermore, the approach and formulation employed in previous works leads to the condition that all the plastic work is completely dissipated. This, however, is in contradiction with experimental evidence, from which it emerges that part of the plastic work is used for producing residual stresses in the lattice, which, when phenomenologically considered, causes hardening. Both limitations were excluded from the present formulations.

Details of this research summarized above will be presented in an interim scientific report, which is presently in preparation.

In the second approach, work has proceeded on the formulation of the governing equations for a beam of arbitrary initial curvature with unconstrained finite strain kinematics compounded with thermoelastic and viscoelastic constitutive relations.

A brief outline of future work is presented in the next section.

#### Future Research

As a consequence of these formulations, computational methods may be constructed. The incremental differential theorems lead to various finite difference methods. However, an integral theorem like the principle of the rate of virtual power calls for implementation by a finite element method. The discretization of the solid or shell-like structure into finite elements and their systematic insertion into the integral theorems may yield a system of nodal motion differential equations. Numerous such applications are likely to be derived where large thermomechanical loads are anticipated.